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Kleinknecht, A.H.; van Montfort, C.A.G.M.; Brouwer, E.

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Alfred Kleinknecht
Kees van Montfort
Erik Brouwer

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How consistent are innovation indicators?
A factor analysis of CIS data

by
Alfred Kleinknecht*, Kees van Montfort** & Erik Brouwer***

* Delft University of Technology, Faculty Technology, Policy and Management,
Correspondence address until August 2000:
Kanaalweg 2 B, NL-2628 EB Delft
New correspondence address after 25 August 2000:
Jaffalaan 5, NL-2628 BX Delft
a.kleinknecht@tbm.tudelft.nl
** Department of Econometrics, Free University, Amsterdam
***University of Amsterdam, SEO, Foundation for Economic Research

Abstract:
We discuss the strengths and weaknesses of five alternative innovation indicators: R&D, patent applications, total innovation expenditure and shares in sales taken by imitative and by innovative products as they were measured in the 1992 Community Innovation Survey (CIS) in the Netherlands. We conclude that the two most commonly used indicators (R&D and patent applications) have more (and more severe) weaknesses than is often assumed. Moreover, our factor analysis suggests that there is little correlation between these indicators. This underlines the empirical relevance of various sources of bias of innovation indicators as discussed in this paper.

Keywords: R&D, innovative output, total innovation expenditure, patents, factor analysis.

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1 Introduction

Public policy is increasingly concerned about promoting innovation in order to stimulate economic growth, employment and ecological sustainability. Clearly, there is an increasing need to measure and assess innovation and technological change and to increase our knowledge about driving forces behind innovation and socio-economic consequences of innovation. In the past, publicly available, internationally comparable and reliable data on innovation and technological change have been extremely sparse. As a consequence, many interesting theoretical hypotheses have been poorly examined and political decision making has often been guided by intuition rather than by knowledge.

However, since the beginning of the 1990s, notably since the 1992 pilot round of the *Community Innovation Survey* (CIS), some progress has been made in collecting micro-data on innovation. The CIS undertook a more elaborate measurement of innovation inputs (total innovation expenditure, including non-R&D expenditure), as well as an attempt to measure newly developed indicators of the output side of the innovation process. As compared to R&D and patents, the new output indicators have the advantage that they measure innovation directly, i.e. they measure market introduction.

Sections 2 and 3 discuss the strengths, weaknesses and possible biases of existing and newly emerging innovation indicators, drawing from our experience with the data collection during the 1990's. We give special attention to R&D and patents, total expenditure on product innovation and sales of imitative and innovative products. The factor analysis of Dutch firm-level data from CIS-I (1992) in section 4 underlines that the choice between innovation indicators does matter. Section 5 covers our conclusions.

2 Traditional innovation indicators: their strengths and weaknesses

2.1 R&D efforts

R&D efforts can be measured by expenditures on R&D (as a percentage of a firm's total sales) or by the number of persons carrying out R&D (as a percentage of total employment in a firm). Being available since the 1950s, R&D figures still are the most popular innovation indicator.

Advantages

The R&D indicator has several strong points. First, data on R&D have been collected at regular intervals since the 1950s. R&D data are compiled by the secretariat of the OECD that undertook numerous efforts towards international harmonisation of data collection. Besides data by sectors, time series are available and the data are frequently used by policy analysts for inter-country, inter-industry and inter-firm comparisons. While it is often complained that R&D data can not be split by technical field, it is, in recent years, increasingly possible to subdivide R&D by product versus process efforts. This subdivision is very important for empirical analyses of the impact of innovation on firm performance since product (other than process) innovation efforts seem to be crucial for firm growth, employment and profits (see e.g. Brouwer, Kleinknecht and Reijnen 1993; Geroski et al. 1993; or Bleichinger et al. 1997). Finally, analysis of intersectoral technology flows is, in principle, possible (although not easily done).

Weaknesses

Although R&D data measure an important input to new knowledge production, they have a number of disadvantages. First, R&D is only an input of the innovation process. Since inputs can be used more or less efficiently, it would be desirable to have indicators of the output side of the innovation process. In addition, R&D is only one out of several inputs. Other (non-R&D) inputs include product design, trial production, market analysis, training of employees, or investment in fixed assets related to product innovation. An illustration of the relative importance of non-R&D innovation expenditures in German manufacturing is given by Felder et al. (1996). Brouwer and Kleinknecht (1997) report an estimate of product innovation expenditures for manufacturing *and* service industries in The Netherlands. They show that product- (and service-) related R&D is only about one quarter of the total product innovation expenditure in Dutch manufacturing and service industries in 1992, the share of R&D in total innovation expenditure being higher in manufacturing than in services. This confirms, at a national scale, what has been expected from many individual case studies: R&D data tend to underestimate innovation in services.

Another problem with R&D data relates to measurement. There is evidence that standard R&D surveys tend to severely underestimate the small-scale and often informal R&D activities in smaller firms. While, using an identical Frascati-definition of R&D, innovation surveys that include somehow simplified questions about R&D usually find many more small and medium-sized firms reporting some R&D than is found in the official surveys in which more complicated questionnaires are used (Kleinknecht 1987). In The Netherlands, it also turned out that the numbers of firms that receive R&D subsidies tremendously exceed the numbers of R&D performing firms according to the official R&D survey (Kleinknecht and Reijnen 1991). The undercounting of small firm R&D has obvious consequences for our judgement about the relationship between firm size and innovation, and it may still be disturbing for comparisons across sectors, regions or even countries as far as shares of small firms differ between the units to be compared.

Additional measurement problems relate to the interpretation of the definition of R&D. When testing a draft version of the harmonised Community Innovation Survey (CIS) in five different countries, we discovered that, in some countries, there are problems with the lengthy and complex Frascati definition of R&D. Many firms tend not to read the detailed definitions. For example, in Norway, a number of respondents reported intuitively more R&D than they wished to report once they had read the Frascati-definition (Kleinknecht 1993, pp. 158).

Another problem with R&D data relates to the need for secrecy that often hampers research. Notably in small countries like The Netherlands which have a few very big firms, R&D data will often have to be published at relatively high levels of sectoral aggregation in order to prevent inferences about the very large firms. This poses a great problem, since many topics in innovation research can only be addressed meaningfully if at least fairly disaggregated sector data (but preferably: micro-data) are available.

Finally, splitting of R&D data by regions tends to be hard to do. In some cases, all of a company's R&D may be reported by the holding company, whereas the R&D efforts are actually scattered all over the country. In more de-centralised multi-plant companies, it may happen that some data reporting units do little or no R&D themselves but they do take advantage of R&D done by other firms in the conglomerate. A similar problem can even arise at the country level, also known as the 'Singapore effect': Singapore itself has a fairly modest R&D potential, but there is nonetheless a high rate of new product introduction by affiliates of multinationals which take advantage of R&D done by their mother or sister companies elsewhere in the world.

2.2 Patents and patent applications

Patents are often used as an (intermediate) output measure of innovation. Compared to R&D, the use of patent data has always been a second best solution, in spite of the use of superior patenting databases that have become available in the course of time (see the survey by Griliches 1990).

Advantages

Very long historical time series are available, and these series show only minor disturbances by occasional changes of patent laws or by major law court decisions. Patent databases are publicly available, and contain classifications by technical field. Patent records offer the most comprehensive and detailed overview of technical knowledge at a certain point in time. It is even possible to assess the relative importance of patents by means of citation analyses. Regional disaggregation of patent data is also possible, although this meets difficulties in some cases (e.g. very large firms).

Weaknesses

It is obvious that the patent indicator misses many non-patented inventions and innovations, and some types of technology are not patentable. On the other hand, what is the share of patents that is never translated into commercialised viable products or processes? And can this share be assumed to be constant across branches or firm size classes? Moreover in some cases, patent figures can be obscured by strategic behaviour: A firm will not commercialise the patent but use it to prevent that a competitor can patent and use it.

Moreover, two other (minor) shortcomings should be mentioned: (1) patents are not always easily classified by economically relevant industry or product groupings; (2) some patents can reflect minor improvements of little economic value, while others prove extremely valuable and the question is whether such differences are adequately captured by citation analyses.

While such arguments are well-known, there are some recent new insights with respect to the propensity to patent a product innovation. It has often been argued that the propensity to patent may differ across industries depending on the relative costs of innovation versus imitation. If imitation costs are relatively low, as for example in the pharmaceutical industry, firms will have a strong incentive to seek patent protection. The opposite holds if imitation costs are relatively high. By the way, findings by Levin et al. (1977) for the US and the study by Brouwer & Kleinknecht (1999) for The Netherlands suggest that, on average, firms do not consider patent protection as the most important means to appropriate benefits from innovation. Factors such as 'a time lead on competitors', 'secrecy' or 'keeping qualified people in the firm' tend to rank much higher.

Recently, Arundel & Kabla (1998) have demonstrated that there are indeed considerably differences in the propensity to patent across sectors. Their findings from a database of Europe's largest firms have been independently confirmed by Brouwer & Kleinknecht (1999), using the CIS-I (1992) database that is representative of firms with 10 and more workers in The Netherlands. In a more detailed multivariate analysis, the latter confronted actual patenting rates of firms to a measure of innovative output, finding significant differences in the propensity to patent in three dimensions, i.e.:

- Smaller firms have a lower probability to apply for at least one patent; however, given that they do so, they apply for higher numbers of patents. Apparently, small firms have a threshold problem, the first patent being the most expensive in terms of information costs.
- Firms that collaborate on R&D are patenting more intensively than is done by non-collaborators. Seemingly firms wish to protect the most precious parts of their knowledge before engaging into collaboration with a partner.
- Firms in high technological opportunity sectors tend to have a higher propensity to patent than firms in low technological opportunity sectors.

The above implies that when using patents as an innovation indicator, we will underestimate innovation in low technological opportunity sectors and among innovators that do not collaborate on R&D. Moreover, we underestimate the rate of small innovators, while overestimating their innovation intensity.

Summarising the above and reminding notably the severe measurement problems with respect to R&D and the recent findings on the propensity to patent, it can be concluded that these two indicators are probably worse than is their image. It is therefore a good message that some alternatives became recently available. These will be discussed in the following.

3 New innovation indicators

New indicators include total innovation expenditures, shares of imitative and innovative products in a firm's total sales, new product announcements in trade and technical journals, and significant (or basic) innovations,

3.1 Total innovation expenditures

As opposed to R&D expenditures, figures on total innovation expenditures cover a larger variety of inputs into the innovation process. A first attempt to measure non-R&D innovation expenditure has been undertaken, at a European scale, during the first round of the Community Innovation Survey (CIS). Estimates for The Netherlands by Brouwer & Kleinknecht (1997) suggest that R&D budgets are just about one quarter of total product innovation expenditures, about half of these expenditures being taken by investments in fixed assets related to product innovation. Moreover, fixed investment related to product innovation takes a much higher share in services than in manufacturing. Clearly, the new indicator is much richer than the classical R&D figures. However, it needs to be emphasised that questions about non-R&D inputs are difficult to answer accurately since many firms do not keep such records. As a consequence, item non-response rates were high and many firms indicated, in a separate question, that their answers were 'rough estimates' rather than 'fairly exact figures'. Inclusion of this indicator in a questionnaire is likely to have a negative impact on the overall response rate.

3.2 Sales of imitative and innovative products

This indicator is based on a firm's assessment in a postal survey of new product introductions. Firms are asked to subdivide their present product range into products that, during the last three years,

- remained essentially unchanged,
- underwent incremental change,
- were subject to radical change or were introduced entirely new.

Subsequently, they are asked to estimate the share of these three categories of product in their last year's total sales. There are two other interesting dimensions in these data. First, one can ask whether the new products were 'new to the firm' (i.e. already known in the firms market) or whether they were 'new to the ***market'*** (i.e. not previously introduced by a competitor). The former category can be interpreted as imitations, the latter as 'true' innovations. Secondly, we obtain figures about incremental improvements versus 'full' innovations.

Advantages

This is a direct measure of successful innovation, measuring innovations that were introduced into the market and that resulted in a positive cash-flow. The distinction between 'true' innovations ('new to the *market*') and imitative innovations ('new to the firm') as well as the distinction between incremental and 'full' innovations offers new research possibilities that did not exist as long as we were confined to R&D data. We can, for example, estimate multivariate models that relate a firm's R&D input to its innovative output. This can say something about the more or less efficient use of R&D inputs and about factors that influence that relationship (see several contributions in Stoneman 1995; or in

Kleinknecht, 1996). Another advantage is that, as far as large firms respond to innovation surveys at a more disaggregated level, regional disaggregation of output indicators can be done more easily than in the case of R&D figures. Finally, although the measurement of innovation output focused on manufacturing in the recent round of the CIS, extension to services sectors is possible with only minor modifications as has been demonstrated in The Netherlands (see Brouwer and Kleinknecht 1995).

Weaknesses

Indicators from postal innovation surveys sometimes suffer from low response rates (and response can be selective), which can make it difficult to produce figures that can be interpreted as national totals. In this context, it is another weakness that many firms can give only 'rough estimates' of the share in sales of innovative products. Moreover, figures on shares in sales of innovative products may be sensitive to the business cycle (which may be misleading in some circumstances), and intersectoral technology flows are hard to assess with this indicator. Inter-firm and inter-country comparisons are possible but notably intersectoral comparisons may be problematic since the length of life cycles differs between branches. Branches which typically have products with shorter life cycles will tend to have (ceteris paribus) higher rates of new product introduction, and vice versa. This implies that, in innovation surveys, one should always include a question about the average length of the life cycle of the firm's most important products. This information is an important control variable in multivariate estimates, and, ideally, one should correct tables about sectoral differences in new product introduction by the average length of life cycles by sector. Moreover, during the first rounds of the CIS, it was not clearly defined what was understood under 'new to the ***market':*** Was the relevant market the regional, national, European or World market? There are indications that smaller firms report more of their new products as 'new to the market', since they operate in regional or national markets, while large and export intensive firms may take the World market as their reference point.

3.3 New product announcements

Besides asking for shares in sales of newly introduced products, it has also been tried to measure innovative output by systematically screening new product announcements in trade and technical journals. Such a data collection has been undertaken by The Futures Group for the US Small Business Administration in 1982 and has lead to a number of interesting new studies of the relationship of firm size and market structure and innovation (see for a survey Acs & Audretsch 1993). Early in the 1990s, several attempts to collect similar data in Europe have been undertaken (see several chapters in Kleinknecht and Bain 1993).

Advantages

As the previous indicator, this is a direct measure of the market introduction of new products or services. The data are relatively cheap to collect as students can do it, and firms are not bothered with time consuming questionnaires, i.e. data collection can, in principle, be performed without contacting firms and we have no non-response problems. Since the data are taken from published sources, the subsequent use of the data is not hampered by privacy problems. It is possible to split the data by type of innovation (e.g. new products, improvements of existing products, product differentiation etc.), by degree of complexity or other dimensions.

It is an important advantage of these data that it allows covering innovation in (very) small firms at reasonable cost (firms below 10 or 20 employees tend to be neglected in postal surveys, in order to keep sample sizes and survey costs within reasonable limits). Data collection results in addresses of innovators that can be valuable for various purposes (e.g. for in-depth case studies). It is even possible to make comparisons over time, because the database can, in principle, be extended to the past (as far as the same journals - with the same formula - are available). A broad coverage of sectors (including services) is possible, while many other indicators tend to be confined to manufacturing. Intersectoral technology flows (from innovation 'producers' to innovation users) can be identified relatively easily. Finally, reliable regional disaggregation of data (which is so difficult in the case of R&D) is possible. New products announced in trade journals are, in principle, assigned to the unit that brings the new product on the market. Although this unit need not always be identical to the unit which developed the new products, this indicator may give a more realistic picture of the regional spread of innovation activity than is given by R&D figures.

Weaknesses

New product counts depend on adequate journal selection. It is important to select the relevant journals, but the number of innovations will depend on the number of journals covered. Therefore inter-country comparisons have to be limited to comparison of ratio's (e.g. the share of small firms, of certain sectors or regions in the total innovation volume). It also means that statistical properties of the database appear dubious since standard statistical procedures (clearly defined population and sample) are not applicable. Thereby publication policies of journals and the public relations policy of firms may influence data collection. Only published products and service innovations are measured. We assume that firms have an incentive to make their product and service innovations public and that they use the possibility to have them reported in a journal. This incentive will not hold for internal process innovations. This means that process innovations are not adequately covered. This latter shortcoming is not crucial, because the impact of the latter is being captured somehow with conventional productivity figures. Finally, in some market niches (with very small numbers of potential buyers), a firm may refrain from publication of new products in journals, other publication channels being more efficient.

3.4 Significant (or basic) innovations

Significant (or basic) innovations are also an output measure of innovation. This indicator has a certain similarity with counting of innovations using trade journals.

Advantages

This indicator is a direct measure of the market introduction of innovations. Firms are not bothered with time consuming questionnaires, i.e. data collection can be performed without contacting firms, because experts give there opinion about the significance of innovations. It is even a useful indicator of paradigm changes.

Weaknesses

Significant (or basic) indicators depend on the quality of experts judgements. All experts have their own subjective point of view. It also means that statistical properties of the database appear dubious since standard statistical procedures (clearly defined population and sample) are not applicable. The costs of data collection may be high because (other than in the case of literature-based innovation output indicators) experts are needed. The approach of significant (or basic) innovations as an indicator misses (or understates) incremental innovations and it also excludes unsuccessful innovations. Moreover, a good assessment of major innovations is possible only ex-post (from historical distance). Innovations can only be identified as basic innovations after some time.

4 Analysis

We now proceed to a factor analysis of the following five innovation indicators that were collected in the Netherlands as part of the 1992 Community Innovation Survey:

1. Logarithm of R&D-man years;
2. Numbers of European patent applications;
3. Expenditure on innovation (including non-R&D-expenditure and investment in fixed assets related to product or service innovations);
4. Logarithm of sales of innovative products 'new to *the firm*' (i.e. already known in the market), which may be interpreted as an indicator of imitation;
5. Logarithm of sales of innovative products 'new to the *market*' (i.e. not introduced earlier by a competitor), which may be interpreted as an indicator of 'true' innovation.

All five indicators cover the year 1992. The CIS covered firms with 10 and more employees in all manufacturing and service sectors. The sample covers some 8.000 firms with a response rate of 50.8%. The available information on the non-responding firms indicates that they do not differ systematically from the respondents (for details see Brouwer and Kleinknecht, 1995).

The CIS questionnaire consisted of two parts. The first part asked for general information on the firm (branch of principal activity, sales, exports, employment, etc).. The second part contained questions on innovation and R&D. At the end of part one, firms were asked the following three questions:

a. Did your firm develop any technologically changed *products* during 1990-1992?
b. Did your firm develop any technologically changed *processes* during 1990-1992?
c. Does your firm *plan* to develop any technologically changed products or processes in the years 1993-1995?

Only firms that answered at least one of these three questions in the affirmative were asked to fill in the second part (on R&D and innovation). In other words, firms that were 'non-innovators' according to all three questions were allowed to drop most of the second part (on innovation). This procedure should help to avoid that many non-innovators would become non-respondents since they experienced large parts of the questionnaire as irrelevant. Of course, only the innovators that filled in the full questionnaire are interesting in the context of our analysis.

As should have become clear from our above discussion, the five types of innovation indicator represent different aspects of innovation, and there are good reasons to expect that at least some of them will deviate from the others. In this section we investigate whether we can distinguish specific groups of indicators that are quite similar or quite different, using factor analysis. The main idea behind factor analysis is that it may be possible to describe a set of variables in terms of a smaller number of common factors, and hence elucidate the relationship between these variables (see e.g. Manly, 1986). However, it must be stressed that factor analysis does not always work in the sense that a large number of original variables are reduced to a small number of transformed variables.

This paper uses the five above-mentioned indicators as original variables and two common factors:

$Y_1 = A_{11} F_1 + A_{12} F_2 + E_1$

$Y_2 = A_{21} F_1 + A_{22} F_2 + E_2$

$Y_3 = A_{31} F_1 + A_{32} F_2 + E_3$

$Y_4 = A_{41} F_1 + A_{42} F_2 + E_4$

$Y_5 = A_{51} F_1 + A_{52} F_2 + E_5$

, with Y_1 up to Y_5 the five different indicators,
F_1 and F_2 the two common factors,
$A_{11}, \ldots A_{52}$ the unknown factor loadings
and E_1 up to E_5 the unique parts of the different indicators.

Table 1 summarises our findings for the total ***sample.*** As a robustness check we divided our total sample into three groups which should allow to control for specific differences in innovation behaviour between groups of industries:

1. services (496 innovating firms)
2. low technological opportunity sectors within manufacturing (671 innovating firms)
3. high technological opportunity sectors within manufacturing (363 innovating firms)

The division between high and low technological opportunity sectors was motivated by Pavitt's (1984) 'taxonomy' of sectors. Pavitt subdivided manufacturing into 'science based' sectors, 'scale intensive' sectors, 'specialised suppliers' and 'supplier-dominated' sectors. For the purpose of this study, we joined the first three categories into one: high technological opportunity sectors; the supplier-dominated sectors are taken as low technological opportunity sectors, besides services as a third category. For each of these three categories we applied our factor analysis separately. Since it turned out that the results for the three groups hardly differed, we confine our documentation in table 1 to the results for the total sample.

Table 1: Factor loadings of five different innovation indicators and two common factors (total sample, absolute values of innovation indicators)

variables:	factor 1	factor 2
logarithm of total number of R&D man-years	0.75	0.37
numbers of European patent applications	0.77	0.01
expenditure on innovation	0.75	-0.02
logs of sales of innovative products 'new to the firm'	0.09	0.97
logs of sales of innovative products 'new to the market'	0.08	0.29
Percentage explained by common factor	48%	24%

The table shows that the following three variables have large values for the factor loadings of the first common factor but have small values for the factor loadings of the second common factor:

- logarithm of R&D-man years,
- numbers of European patents, and

- expenditure on innovation.

We can conclude that these three indicators may represent the same aspects of innovation, i.e. they tend to be interchangeable. However, the two output indicators (i.e. logs of sales of innovative products 'new to the firm' and 'new to the market') have other values for the first and second common factor. These two indicators contain different aspects of innovation than the former three indicators. In other words: A large number of R&D-man years, large expenditures on innovation and high numbers of European patent applications tend to coincide but a high score on either of the three does not mean that the firm also has high sales of innovative products.

Table 1 shows that the first common factor explains 48% of the variances of the five indicators, while the second explains 24%. As a consequence, about 72% of the variances of the five indicators are explained by the two common factors. These are acceptable percentages for a two-factor model. One could argue against this that we took absolute values of the various indicators. Since large trees catch more wind than small trees, it is not astonishing that large firms have generally higher values on the various indicators than small firms. Obviously, firm size may cause correlation.

We therefore repeated our analysis, replacing the absolute values of the innovation indicators by *relative* values. In other words, we construct the following innovation indicators (for which all observations again relate to 1992):
1. Logarithm of R&D-man years divided by a firm's total number of employees;
2. Numbers of European patent applications divided by a firm's total sales;
3. Expenditure on innovation divided by a firm's total sales;
4. Sales of innovative products 'new to the *firm*' divided by the firm's total sales;
5. Sales of innovative products 'new to the *market'* divided by the firm's total sales.

This correction for size changed our outcomes dramatically. When using *relative* values, the first and second common factors explain each only about 22% of the variances of the five innovation indicators. In other words, there is no significant correlation between the five (relative) innovation indicators, implying that the correlations found in table 1 have been due to one common factor: firm size. This means that all the five indictors of innovation can have different values and are not substitutable.

5 Summary and conclusions

Our discussion of strengths and weaknesses of alternative innovation indicators shows that the choice between these indicators is far from trivial. It depends on what one wants to investigate and on the level of aggregation. In particular, recent research suggests that the two most frequently used indicators (i.e. R&D and patenting) have more (and more severe) shortcomings than is often thought. In many cases, direct measures of innovative output are to be preferred.

At a first glance, our factor analysis of *absolute* values of innovation indicators suggested that there is a clear difference between two groups of indicators:
(1) R&D, total innovation expenditure and patent applications, and,
(2) two types of output indicators.

One could have concluded from this that it would not make much difference which of the three indicators from the first group one happened to use; the indicators from this group would tell us essentially the same story. However, the apparent correlation between the indicators turned out to be mainly caused by one common factor: firm size. Once we normalise for firm size, the correlation disappears. Each of the five relative indicators examined tells us a different story.

For outcomes of innovation studies, it does matter which indicator one happens to use. As outlined in our discussion of strengths and weaknesses of innovation indicators, several indicators have various sources of bias, depending on what is being investigated. Our factor analysis of the relative indicators underlines that the sources of bias discussed in our sections 2 and 3 need to be taken seriously. The choice among the five alternative innovation indicators is a far from trivial problem.

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